CONTEXT IV: NUCLEAR REACTOR TESTING: 1949-1970

Preliminary Review of Nuclear Reactors

The work of "nuclear reactor testing" is best begun with a short introduction to nuclear reactors and related subjects mentioned frequently in this report. Nuclear reactors have several features in common: core, reflector, control elements (ie, rods), coolants,

Core: The core is that part of the reactor consisting of the fuel and control elements, a coolant, and the vessel containing these. The design is such to sustain a chain reaction. Neutrons are less likely to split another atom if they travel at their natural rate of speed, which is in the range of millions of miles per hour. To slow them down, the fissionable fuel, such as uranium, is surrounded by a substance that slows, or **moderates,** the neutrons. Some materials do this well, but others absorb the neutrons, taking them out of play as promoters of the chain reaction.

Reflector: Surrounding the core (of many reactors) is a reflector. One of the challenges in reactor design is to prevent the neutrons from escaping the core and becoming useless to the chain reaction. A single fission event of a uranium atom will produce, on average, about 2.5 neutrons. Each of these are capable of fissioning another atom. If the neutrons escape from the core, they will not be available to continue splitting the uranium atoms. Reflectors bounce the neutrons back into the core of the reactor.

Control Elements: One objective of reactor design is to control the chain reaction at the will of the operator -- to control the rate at which neutrons are produced within the core and thus the rate at which the chain reaction proceeds. Control elements are made of materials that absorb neutrons and slow down the reactivity of the fuel. The elements often are in the shape of rods. Operators move one or more control rods into the midst of the fuel where they absorb the neutrons in just the quantity required by the operator to reduce reactivity or shut down completely.

Heat and Coolants: The supreme reason for requiring perfect control over a chain reaction arises from the fact that every fission of an atom produces a unit of heat. The fissions can occur so fast and in such quantity that the heat can melt the fuel, the moderator, and the container vessel surrounding it. Reactor designers, therefore, must arrange for some reliable method of carrying off the heat.

In the case of reactors intended to generate electricity, the heat is the useful part of the reaction. The coolant carries away the core heat and transfers it to a secondary coolant, which then provides the motive force (ie, steam) to power the turbines of the generation machinery. In many reactors, the coolant can serve a dual function as a moderator.

Reactor "concepts." Reactors can be configured in many possible arrangements and use a variety of materials in any part of its architecture. For example, the coolant can be water, a liquid metal, or gas. A reactor performs differently -- and the engineering is very different -- depending on the type of coolant (or fuel, or moderator, etc). The literature of nuclear reactors refers to a particular combination of nuclear features as a "concept." Each combination performs quite unlike the other choices, so each "concept" must be studied to discover its characteristics, its advantages for any given purpose, and its disadvantages.

"Excursions" and "Transients." As scientists began their post-war research into reactor concepts, they needed to find out just what the safe operating limits of reactors were. For example, how much heat could build up before a fuel element or its cladding would melt? Many of the safety tests conducted at NRTS dealt with "excursions" and "transients," names used to refer to extreme power levels and heat build-up. For various reasons (such as imperfectly manufactured fuel elements, the behavior of the coolant, failed cladding materials, or some other anomaly) the power level in a reactor can rise sharply and unexpectedly. This can produce dangerous quantities of heat. Much of the early testing and research at INL sought to discover the safe operating limits of reactors and the materials of which they were made. It also was important to study how the design of reactor components could eliminate or reduce the occurrence of such episodes, how to predict reactor behavior under various conditions, and how to use instrumentation and safety systems to prevent accidents.

SubTheme: *Reactor Testing, Experimentation, and Development*
INEEL Area: Central Facilities

CFA Site Transitions from the Navy to the AEC: 1950-1954

The AEC "inventors" of the reactor testing station decided that the reactor experiments would take place at locations assigned to the sponsor and selected according to safety and other criteria administered by AEC management. The AEC would then supply support services -- such as security, laundry, warehousing, dosimeter and health services, fire prevention and suppression, transportation to and from Idaho Falls -- to all sponsors from a centralized location.

The NPG complex became that location, equipping the AEC with ready-made buildings, roads, rail spur, yards, security perimeters, electricity, and water from which to launch the rest of the enterprise.

While the transfer of ownership from the Navy to the AEC was still in process, the AEC began evaluating the water supply, building a well for the first reactor experiment, and improving the existing Navy roads and trails. Soon the foundation for the Experimental Breeder Reactor (EBR-I) was under construction. The AEC added new rail spurs and expanded the Scoville electric substation to serve potential reactor sites.

When it came to construction standards and policies, AEC policies were similar to those that governed the armed forces. Shaped by similar congressional mandates and budgets, the AEC required functional and standardized design, ease of construction, safety practices, and careful programmatic and fiscal accounting. Adapting NPG buildings for new uses rather than dismantling them was one way to save funds.[1]

Thus NPG dwellings and other buildings were the first home to for the testing station's many central functions. Some of the houses became construction contractor offices. Site engineers made use of the established military grid used by the Navy to define its territory and adapted it to the new requirements of the testing station.

The red-brick officer's residences, garages, and Marine barracks became offices, lunch rooms and security control centers (CFA-606, -632, and -607 respectively). The Navy bunkhouse (CFA-613) continued to be used as a bunkhouse. One

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[1] United States Department of Energy, *National Register of Historic Places Multiple-Property Documentation Form, Historic, Archaeological and Traditional Cultural Properties of the Hanford Site, Washington* (Richland, Washington: US DOE, February 1997), p. 6.10; see also "Engineering Aspects of the National Reactor Testing Station" (US Atomic Energy Commission, Idaho Operations Office, October 1951), p. 13. Hereafter cited as "Engineering Aspects."

residence (CFA-603) was converted into a dispensary. Despite the changes in use, engineers worked carefully to blend new additions and changes with the old.[2]

Buildings in the Proof Area also were recycled for NRTS missions. In the 1950s site engineers remodeled and joined together several extant buildings near the concussion wall and control tower. These structures were originally assigned individual numbers, such as the oil shed (646) and office (684). A portion of this remodel was a new instrument laboratory, numbered CFA-633, and a new locomotive shed (no longer extant, built in 1951.) By 1987 all of the buildings attached to the old battery wall had been renumbered as CFA-633, and the old 646 and 684 numbers were reassigned to other storage buildings at the CFA. The control tower was logically converted into a fire lookout. The old NPG boiler room (CFA-650), located near the battery wall, required few renovations and continued in use until the 1990s.

Over the years the Navy munitions bunkers were used to store hazardous materials. Their heavy-duty concrete construction and berms provided the same protection from chemical explosions as from munitions explosions. One of the bunkers became the Dosimetry Calibrations Laboratory (CFA-638) in 1969, providing appropriate shielding from background radiation. The NPG locomotive shed and fire station, located south of the old Marine barracks (CFA-606), were converted into craft shops (CFA-654, no longer extant).

The NRTS landlords often pointed proudly to their adaptation and reuse of existing buildings for central services as a mark of their cost-saving efforts. They avoided duplication of basic services and preserved resources better directed to the far more costly requirements for nuclear reactor experiments.[3]

Building contractors patterned new NRTS buildings after established military and industrial designs. Such designs were unembellished and functional, based on engineered building plans with virtually no architectural influences. "Industrial Vernacular" a term later coined by industrial archaeologists and architectural historians, describes this type of architecture.[4] Some of the more permanent

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[2] Architectural drawings, Medical Dispensary Remodel (CFA-603), on file at EROB, INEEL, Idaho Falls, Idaho. See also Julie B. Braun, *LITCO Internal Report, INEL Historic Building Inventory Survey, Phase I* (Idaho Falls: INEL, September 1995).

[3] "Engineering Aspects," p. 13. See also Braun, p. 46.

[4] United States Department of Energy, *National Register of Historic Places Multiple-Property Documentation Form -*

structures, such as offices and early reactor buildings did reflect a few International-Style characteristics of the 1950s, and later Contemporary architecture. Most, however, were plain, box-like structures with flat roofs and concrete walls or corrugated metal siding. These building materials were easily available and relatively inexpensive. Good gravel for concrete existed on-site, and the AEC moved a batch plant from one site to another as needed. The railroad provided easy transport of portland cement, prefabricated metal siding, and framing to each site.[5]

New buildings at the CFA illustrated the site's new nuclear testing mission. Since employees were no longer living on-site (except during the earliest construction phase), none of the new buildings were houses. The domestic-scaled brick Minimal Traditional officers' quarters became a thing of the past. The emphasis was science, engineering, and industry, all of which called for purely functional and impersonal design.

The CFA warehouse (CFA-601) and fire station (CFA-666), built by AEC contractors in 1950 and 1951, set the pattern for the vernacular industrial design that became the norm at the NRTS. The warehouse was a concrete masonry or "pumice block" structure, with a built-up flat roof and concrete slab floor. The AEC's Division of Engineering and Construction designed the building, and regional contractors C.B. Lauch and Associates built it. The fire station, designed and constructed by the same group, used similar materials. A 1951 AEC Engineering Division report took pride in the low cost of these buildings while meeting AEC design requirements at the same time.[6] The cafeteria and bus station, the two buildings constructed specifically for site employees, followed the same functional and impersonal lines. Both were built of concrete block and exhibited no stylistic adornments.

Several smaller CFA support buildings were constructed of material other than concrete. In 1951 most of the pumphouses, storage buildings, generator buildings, and small repair shops were prefabricated structures of corrugated iron cladding on a steel frame. A few were constructed with wood or asbestos shingle siding, and only one of brick after 1950. The fire station generator building

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Historic, Archaeological and Traditional Cultural Properties of the Hanford Site, Washington (Richland, Washington: US DOE, February 1997), p. 6.9, 6.19, 6.25.

[5] Stacy, *Proving the Principle*, p. 38-40.

[6] "Engineering Aspects," p. 13.

(CFA-679) had brick masonry walls, a concrete foundation, and a flat, corrugated-iron sheet roof. The prefabricated metal building became the norm for most later support facilities on the NRTS. These buildings easily could be constructed, dismantled, or moved and recycled for another use. An example was the lead storage building (CFA-687), which was moved from the Idaho Chemical Processing Plant to the CFA in 1952. These structures were -- and still are -- representative of vernacular industrial architecture. Their use emphasizes the change in approach from the Navy to the AEC. Instead of building for permanence, the AEC preferred to erect prefabricated, temporary buildings. In later decades, rapidly changing technology and concerns about radioactive contamination at the nation's nuclear sites increased the AEC's interest in temporary structures.

CFA New Construction Slows Down: 1955-1970

In the 1960s, few buildings were constructed at the CFA. Most of them were storage buildings. Some reflected the changing concerns and issues of the nuclear industry (and its critics), particularly related to the handling of nuclear waste. One of the first radioactive-waste handling facilities at the NRTS was the "Hot" Laundry Facility (CFA-669). Built in 1950, the facility handled all contaminated protective clothing for the entire station. Initially, such low-level waste was regarded in the same light as conventional chemical, or even domestic, waste.

The design of the Laundry Facility reflected this thinking. Radioactively contaminated clothes were washed, and the waste water was carried by a separate sewer line to a trickling-filter sewage plant. The waste entered the same septic tank as other CFA effluent and went to an open drain field. This process had evidently been tested at Los Alamos in 1952 and was considered an effective way to handle low-level waste. Eventually, the hot laundry building, sludge lines, and drain field became thoroughly contaminated. The facility was decontaminated and decommissioned in 1981, when its boiler exploded. A new hot laundry facility (CFA-617) took its place, with its sewage lines going directly to a separate septic tank. The old hot laundry was dismantled in 1992.[7]

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[7] For early national perspective, see A.D. Mackintosh (Superintendent of New Facilities Design and Construction at Oak Ridge National Laboratory), "Architectural Problems in Atomic Labs," *Architectural Forum* (January 1952), p. 159. For CFA laundries, see the Idaho Operations Office, Engineering and Construction Division report by A. L. Biladeau, "Radioactive

As early as 1958, the NRTS reacted to growing national concerns over radioactive fallout from nuclear testing. Site engineers converted an old NPG locker room into a Health and Safety Laboratory (CFA-649) for studying radioactivity levels in area plants and animals. Cow's milk from area dairies, feral and domestic rabbits, wild antelope, and native plant species were studied under laboratory conditions. In 1960 these studies discovered a low level of Iodine-131 in milk from "environmental" cows on nearby farms. Internal reports attributed the rise to an unexplained "special test" conducted at the NRTS.[8]

In 1963, a new and expanded Radiation Environmental Laboratory was built, along with a new Technical Center Laboratory. A 1963 report from the Radiation lab indicated that there had also been an increase of Strontium-90 occurring in cow's milk.[9] Above-ground nuclear testing beyond the boundaries of the NRTS was one likely source of some spikes in Iodine-131 or Strontium-90 levels.[10] Growing calls for protecting the underlying aquifer from continued disposal of radioactive waste prompted NRTS scientists and site managers to voice their concerns to the AEC.

As the nation's attention grew more focused on environmental quality in the 1970s and 1980s, the role of CFA in environmental monitoring and general administration at INEEL eventually grew. As reactors closed down at the other activity centers on the site, reactor-support functions would diminish at the CFA.

SubThemes: *Reactor Testing, Experimentation, and Development*
and
Commercial Reactor Safety

Waste Removal in A Trickling Filter Sewage Plant," May 1953. See also the EG&G Idaho internal technical report by R.D. Browning, "TAN, TRA, and CFA Sewage Treatment Plant Study" (Operational and Capital Projects Engineering, January 1989).

[8] NRTS internal report, "Environmental Monitoring Data for the National Reactor Testing Station, Calendar Year 1959 and 1st Quarter of 1960," p. 1; see also report for Calendar Year 1963.

[9] NRTS internal report, "Environmental Monitoring Data for the National Reactor Testing Station, Calendar Year 1963."

[10] "Environmental Monitoring Report No. 17; Third and Fourth Quarter and Annual Summary, 1965," (Idaho Falls: AEC Idaho Operations Health and Safety Division, NRTS; 1965), p. 1-2.

INEEL Areas: EBR-I, Argonne National Laboratory West

Argonne National Laboratory: An Introduction

The origin of the Argonne National Laboratory places into a national context the purpose of the National Reactor Testing Station.[11]

On December 2, 1942, in the basement of Stagg Field at the University of Chicago, Enrico Fermi and a team of researchers conducted the experiment that produced the world's first self-sustained nuclear chain reaction. The Chicago Pile-1 (CP-1) experiment was part of the Manhattan Project, the government's secret effort to produce an atomic weapon. The scientists who conducted the experiment were members of the Metallurgical Laboratory ("Met Lab"), one of several secret research facilities involved in the bomb project.

The secret project responded to political and scientific events in Europe in the 1930s after Otto Hahn and Fritz Strassman discovered nuclear fission. Physicists world-wide understood that controlled nuclear fission could provide a nearly unlimited source of energy. It could also be designed for bombs with unimaginably powerful explosions. As Hitler advanced, scientists feared that German scientists might be first to discover how to control it for the production of bombs. Several of them petitioned President Franklin Roosevelt to support atomic energy research in the United States. By 1942 the Manhattan Project was underway.

The scientists working on CP-1 knew they would not be able to continue pile research in the basement of Stagg Field. Their assignment, once the chain reaction was achieved, was to experiment with uranium pile size and configuration, searching for the most effective pile design for plutonium production, (an activity that took place at Hanford, Washington). For improved safety, security, and working space, the Met Lab group moved in 1943 to the Argonne Forest Preserve, a site near Chicago. Enrico Fermi was named director of the new Argonne Laboratory.[12]

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[11] For additional background, see Stacy, *Proving the Principle*, Chapter 3, "The Uranium Trail Leads to Idaho," p. 18-27.

[12] Jack M. Holl, *Argonne National Laboratory, 1946-96* (University of Illinois Press, 1997), p. 22-23. Hereafter cited as "Holl, *Argonne*." After the war a larger site in Du Page County, Illinois, became the current location of Argonne National Laboratory.

Manhattan Project scientists had always discussed the future of nuclear research. Atomic science was new. It had potential for power production and other uses, but to advance these, further research was needed in materials, efficiency, operating methods, and safety.

The Manhattan Project laboratories were the likely centers for such research. In 1946, a committee formed by General Leslie Groves, head of the Manhattan Project, recommended distributing various research needs among the existing laboratories and a new one to be located in the Northeast. Argonne would pursue atomic pile, or reactor research. Walter H. Zinn became director after Enrico Fermi moved to Los Alamos.[13]

By August 1, 1946, when President Harry S. Truman signed the Atomic Energy Act, the newly named Argonne National Laboratory (ANL) was one month old. It would focus on two major AEC objectives: developing reactor concepts and the safety of commercial power plant reactors.

Establishing A Test Site for Nuclear Reactors: 1949-1951

One of Walter Zinn's earliest proposals was to design and construct an experimental "breeder" reactor, a reactor that would produce more fuel than it consumed. In those early days of nuclear research, scientists believe that uranium was a scarce resource. Only uranium could be used to fuel reactors, and less than one per cent of natural uranium is fissionable uranium-235 (U-235). A breeder reactor could make uranium scarcity a non-issue. In 1947 the AEC's General Advisory Committee listed the breeder reactor as one of its high-priority projects.

Zinn and others realized that reactor experiments were too dangerous to expose large population centers to possible accidents. The AEC Reactor Safeguards Committee recommended in 1949 that reactor experiments take place at a remote location. After a search for a suitable location, the AEC settled on Idaho's Navy Proving Ground and set out to transform it as a National Reactor Testing Station.[14]

Having settled this matter, the AEC was ready to

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[13] "Atomic pile" was the early term for a reactor, coined because the materials used in the chain reaction experiments were piled on top of each other. The word "reactor" came into use after World War II. Holl, *Argonne*, p. 7, 35-44.

[14] Stacy, *Proving the Principle*, p. 26-27.

execute its reactor-research priorities. Argonne became one of the first clients of the NRTS, responsible for Zinn's breeder reactor experiment, sometimes referred to by his colleagues as "Zinn's infernal pile."

Experimental Breeder Reactor-I (EBR-I)

The Experimental Breeder Reactor (EBR-I), the first reactor constructed at the NRTS, was located in the southwest corner of the site south of U.S. Highway 20/26). Zinn selected the location after a test well began to produce water. At the time, site engineers did not realize that the Snake River Plain aquifer underlaid nearly the entire NRTS site and could have supplied water just about anywhere.

Construction of EBR-I began early in 1950, although a local contractor had poured building foundations in the fall of 1949 to expedite the project. The reactor design, developed at Argonne, already had been approved by the AEC. The Austin Company of Cleveland, Ohio, was architect/engineer. The Bechtel Corporation of San Francisco was named construction contractor and took over construction in the spring of 1950.[15]

The multi-level building, completed in April 1951, was made of steel, brick, and concrete. A single building housed the reactor and control room, as well as utilities and the equipment used for handling, storing, and cleaning nuclear fuel elements. The building, 122 feet long by 77 feet wide, included a basement, main floor, and mezzanine level. It was fifty feet high, with subgrade areas thirty feet deep. The project cost $2,500,000.[16]

By January 1951, the building was ready for action. A team of nine scientists arrived at the NRTS from ANL to assemble the reactor. The reactor was expected to prove the validity of the breeding principle and demonstrate the use

[15] Richard G. Hewlett & Francis Duncan, *Atomic Shield, 1947-1952: Volume II of a History of the United States Atomic Energy Commission* (University Park, Penn.: Pennsylvania State University Press, 1969) p. 495-496; Holl, *Argonne*, p. 87; "Breeder Design Completed, Contractor Selected," *Nucleonics* (January 1950), p. 93.

[16] "Breeder Design Completed, Contractor Selected," *Nucleonics* (January 1950), p. 93.; and E.W. Kendall, D.K. Wang, *Decontamination and Decommissioning of the EBR-I Complex, Final Report* (Idaho Falls: Aerojet Nuclear Company Report ANCR-1242, July 1975), p. 7.

of liquid metal as a coolant. Unmoderated, the reactor was cooled by a eutectic potassium-sodium alloy, NaK. The reactor was small, with a core the size of a "regulation football." The creation of plutonium (breeding) was to occur in two "blankets" of uranium-238 (U-238) surrounding the core. The reactor was operated with twelve stainless-steel-jacketed U-238 control rods, eight of which also functioned as safety rods.[17]

Once the team had assembled the reactor and installed the fuel, it was time to bring the reactor to criticality. Walter Zinn arrived in May 1951 to begin criticality tests. Unfortunately the first test failed. More uranium fuel was needed. Finally, on August 24, the reactor went critical. Zinn's associate Harold Lichtenberger continued to run tests until late December.[18]

On December 20, 1951, energy generated by EBR-I lit four light bulbs in the reactor building -- the first time a nuclear plant had ever produced electricity. The next evening, the reactor provided electrical power for the entire reactor building. The Argonne team had demonstrated that nuclear power could be a source of electricity.[19]

Despite the historic lighting of the four light bulbs, electric power production was not EBR-I's primary mission. Later experiments with its original core (Mark I) and a later core (Mark II) went on to demonstrate the breeder principle: the reactor could produced as much fissionable material as it used. The AEC announced this landmark in June 1953, after core and blanket samples had been examined.[20]

EBR-I's success in breeding fuel also led to the construction of a commercial breeder reactor. In 1956, Detroit Edison began building the Enrico Fermi reactor at Lagoona Beach, Michigan, on Lake Michigan near Detroit.

Boiling Water Reactor Experiments (BORAX).

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[17] W.H. Zinn, "Basic Problems in Central-Station Nuclear Power," *Nucleonics* (September, 1952), p. 10-13; Robert L. Loftness, *Nuclear Power Plants: Design, Operating Experience, and Economics* (Princeton, New Jersey: D. Van Nostrand Company, Inc., 1964), p. 335. Hereafter cited as "Loftness, *Nuclear Power Plants.*"

[18] "Critical" means that the reactor is able to achieve the nuclear chain reaction; "criticality" is the point at which the reactor is just capable of sustaining a chain reaction.

[19] Stacy, *Proving the Principle*, p. 64-66.

[20] Stacy, *Proving the Principle*, p. 135.

In 1952 Argonne scientist Samuel Untermeyer suggested that steam formation in the core of a light-water reactor during a power excursion (sudden rapid rise in the power level of a reactor) might shut down the reactor. He wondered if boiling water could be used as a reactor control mechanism.[21]

His theory was that boiling produced a negative coefficient; that is, as the temperature rises, reactivity decreases. Steam bubbles decrease the water's effectiveness as a moderator. As more bubbles are formed, the reactivity slows until the reactor shuts itself down. This theory was contrary to the widely accepted belief that steam bubbles in a reactor core would cause instability. Untermeyer presented his idea to Walter Zinn, who supported a series of experiments with boiling water reactors (BORAX) at the NRTS. The first experiments in the BORAX series began in the summer of 1953.[22]

BORAX-I was an open-top boiling water reactor located about a half mile northwest of EBR-1. No building was constructed to contain the reactor. The core was placed in a ten-foot diameter shield tank surrounded by a shield of soil piled ten feet deep and layered at a 45-degree angle. Access to the reactor was from an exterior stairway and platform. During the experiments, personnel were in a control trailer located outside the immediate area.

Arrington Construction built the facility in May 1953. The first in a series of more than 200 experiments began immediately. BORAX-I demonstrated that boiling-water reactors of the same or similar design would shut down if the power were suddenly increased. During the experiments clouds of steam and streams of water shot up from the reactor core as high as fifty feet. R.O. Haroldsen, who was present for the experiments, said that when the BORAX-I experiments were running, motorists on the highway could

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[21] "Light water" is ordinary water (H_2O). As a moderator, it slows down fast-moving neutrons and helps maintain the chain reaction. It also absorbs some neutrons, so light-water reactors require enriched uranium, which has more neutrons than natural uranium. Reactors that use "heavy" water (D_2O), which does not absorb neutrons, can operate with natural uranium. See Richard Wolfson, *Nuclear Choices* (Cambridge: MIT, 1991), p. 155-160.

[22] Holl, *Argonne*, p. 118; Andrew W. Kramer, *Understanding the Nuclear Reactor* (Barrington, Illinois: Technical Publishing Co., 1970), p. 37, 70.

observe the steam and water shooting out of the top of the reactor and reported that the Arco Desert had produced a new Old Faithful.[23]

The last BORAX-I experiment took place in July 1954. It was designed to push the reactor to its limits, that is, to destroy it. On July 22, a crowd of scientists and AEC officials gathered to observe. When the crew in the control trailer quickly removed the excursion rod, the sudden change caused a tremendous steam explosion. Although the reactor runaway was planned -- all BORAX-I experiments involved a runaway reactor -- the explosion was something of a surprise. Debris, including reactor rods, plywood sheets, and dirt, shot high into the air. The guests and a number of workers were told to take shelter while a cloud containing small amounts of radioactivity passed over the site.

The results of the final experiment were regarded as inconclusive, but BORAX-I demonstrated that boiling water in the reactor core did not cause instability. A later series of experiments with boiling water reactors (the SPERT tests, discussed later in this report) included modifications of the reactor design to safeguard against excursions.[24]

The BORAX-I reactor debris was buried in place -- entombed. The uncontaminated control equipment was salvaged for use in a later series of BORAX experiments. In the fall of 1954 a site a short distance from BORAX-I was selected as the location for the remaining BORAX experiments.

The early BORAX experiments contributed to the design of Argonne's Experimental Boiling Water Reactor (EBWR), the country's first power production pilot plant. EBWR, which operated at the Argonne site in Illinois from 1956 to 1967, successfully supplied power for the national laboratory in 1966.[25]

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[23] J.R. Dietrich and D.C. Laymans, *Transient and Steady State Characteristics of a Boiling Reactor: The Borax Experiments, 1953*, ANL-5211, February 1954; Holl, *Argonne*, p. 118; Ben Plastino, *Coming of Age: Idaho Falls and the Idaho National Engineering Laboratory, 1949-1990* (Idaho Falls: Margaret Plastino, 1998), p. 64.

[24] Holl, *Argonne*, p. 199-121; Loftness, *Nuclear Power Plants*, p. 156-158; Richard L. Doan, "Two Decades of Reactor Safety Evaluation," Memorial lecture in honor of Dr. C. Rogers McCullough, prepared for delivery at the Winter Meeting of the American Nuclear Society (Washington, D.C.: November 15-18, 1970), p. 5.

[25] Argonne National Laboratory, *Frontiers, Research*

The later experiments in the BORAX series (BORAX-II through BORAX-V) were housed in a prefabricated corrugated metal reactor building erected in late 1954 by the Morrison-Knudsen Company a short distance from the site of BORAX-I. A turbine generator brought in for experiments with power production was placed in a separate building, also made of prefabricated corrugated metal.[26]

BORAX-II and BORAX-IV (1954-1955 and 1956-1958 respectively) tested various core combinations and fuel elements. The BORAX-III series, operated in 1955, tested the reactor's power production capabilities. For these, researchers installed the turbine generator for the experiments. According to R.J. Haroldsen, the team scrounged up an old "wet steam" turbine at an abandoned mining site in New Mexico to use for the power production tests. On July 17, 1955, BORAX-III was patched into the Utah Power & Light power grid. For two hours (11 p.m. to 1 a.m.) BORAX-III produced power for the town of Arco, part of the CFA, and the BORAX reactor complex. Although the power to Arco from BORAX-III was discontinued after the first brief run, BORAX-III continued to supply power for the BORAX complex and the CFA whenever it was running. It ceased operating later in 1955.[27]

BORAX-V, the final experiment in the BORAX series, operated from 1962 to 1964. Although BORAX-V was housed in the same reactor building as the earlier experiments, the structure and the reactor both were modified. The original reactor vessel was buried in place, covered with a deep layer of sand, and capped with concrete. A new reactor vessel was placed in a new addition to the reactor building.

Highlights, 1946-1996 (ANL 1996), p. 16; Loftness, *Nuclear Power Plants*, p. 167-213.

[26] The two buildings and associated support structures (including a redwood cooling tower and a guardhouse) were located in an area about .75 mile north of EBR-I. A control trailer was located about one-half mile from the BORAX area for BORAX II-IV. A control building was built outside the EBR-I complex for BORAX-V. D.L. Smith, *Decontamination and Decommissioning Plan for the BORAX-V Facility*. (Idaho Falls: EG&G Idaho, Inc., Nov. 1988).

[27] Glenn R. Rodman, *Final Report of the Decontamination and Dismantlement of the BORAX-V Facility Reactor Building* (Idaho Falls: INEL, Inactive Sites Dept., Lockheed Martin Idaho Technologies Company, INEL-96/0325, May 1997), p. 1-2; Loftness, *Nuclear Power Plants*, p. 2-4; Holl, *Argonne*, p. 139; Plastino, p. 64.

The purpose of BORAX-V was to demonstrate the feasibility of producing integral superheated steam in a reactor facility. "Integral" means that the boiling water and the superheated ("dry") steam are produced in the same core. It was thought that superheated steam would prove more efficient and economical than a simple boiling water reactor system. BORAX-V went critical on February 9, 1962, and produced its first superheated steam on October 1963. During the course of experiments, BORAX-V tested the safety and effectiveness of superheated steam. The tests also examined safety problems related to damaged or corrupted fuel elements. At the end of a number of successful runs, BORAX-V was placed on stand-by in late 1964.[28]

The BORAX experiments helped persuade the AEC that the deliberate inducement of power excursions and the deliberate withdrawal of coolant to a reactor could be tested under controlled conditions without disaster. Many more followed BORAX. Such tests yielded valuable safety information which, at a time when the modeling capability of computers was long into the future, could be acquired no other way. They established for the NRTS a unique and primary role in the development of safe nuclear power reactors. BORAX proved the principle enabling pressurized water reactors to be further developed.[29]

The Argonne-West Facility Grows: 1955-1965

In addition to the landmark event of BORAX-III lighting the town of Arco, the year 1955 also brought a milestone of another sort to Argonne's Idaho Division.[30] In November, EBR-I experienced an unintentional core meltdown -- the first such accident in a nuclear reactor. Walter Zinn viewed the accident as a source of important information about fuel rod configuration and operating procedures, but the AEC's failure to publicize the accident gave rise to questions

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[28] Rodman, p. 2; Loftness, *Nuclear Power Plants*, p. 217-218.

[29] Stacy, *Proving the Principle*, p. 132.

[30] The name "ANL-West" did not come into usage until later. According to Richard Lindsay, ANL-West Public Information Officer, "Idaho Division" and "Idaho Branch Administration" were used to describe different activities, and the similarity of the names caused confusion. He believes that ANL-West was used unofficially to describe all of the operations and may have been made an official name when the headquarters lab was reorganized.

about reactor safety and the credibility of the AEC.[31]

Nevertheless, Argonne expanded its facilities at the NRTS. A second breeder reactor, EBR-II, was proposed by Walter Zinn and approved by the AEC in 1954. Based on experimental results and operating experience with EBR-I, EBR-II would be an intermediate-sized reactor, capable of producing twenty megawatts of electricity. Design of EBR-II began in 1955 and construction began late in 1957.

Zinn located the new complex at "Site 16," on the eastern edge of the NRTS site, a location nearest to Idaho Falls. It soon was known as Argonne-West or ANL-West. Argonne planned to operate EBR-II for several years and knew that there would be frequent visits from scientists based in Chicago. Time saved in driving to and from Idaho Falls, after flying in from Chicago, was the most important factor in the site selection.[32]

Although Argonne was poised to lead the nuclear industry in the development of breeder reactors, differences of opinion between AEC and Argonne somewhat stunted Argonne's role in the development of major test reactors. In 1965, the AEC canceled Argonne's Fast Reactor Test Facility that had been approved in 1962. To the dismay of Argonne supporters, the AEC went on to build the Fast Flux Test Facility at Hanford, Washington. When the AEC decided to focus its resources on a breeder concept known as the Liquid Metal Fast Breeder Reactor (LMFBR), Argonne's assignment was to do safety research in its support, using EBR-II and its other facilities for that purpose.

EBR-I after 1955.

After EBR-I's accidental melt-down, Argonne examined the reactor core and found that its fuel elements had bowed in the high temperatures. The materials and design had not allowed for heat expansion. When a new core (Mark III) was installed in 1957, design modifications included zirconium spacers in the fuel elements, cluster-mounted control rods, and clamping of the inner core assembly. The modifications prevented unwanted mechanical movement within the assembly, which was seen as the cause of the meltdown. Thus, the accident contributed to the accumulation of knowledge about the safe design of nuclear reactors.

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[31] Stacy, *Proving the Principle*, p. 135-136.

[32] Richard Lindsay, public information officer, ANL-West, Personal communication with Elizabeth Jacox, Sept. 2, 1997.

Five years later, in 1962, a new core (Mark IV) was installed, loaded with plutonium fuel elements, the first plutonium fuel elements used in a power reactor. EBR-I operated successfully with the Mark IV core until it was shut down in 1964.[33]

Argonne West Reactors 1955-1970

Zero Power Reactor III (ZPR-III). The Argonne-West complex expanded steadily with the addition of several new reactors and their support facilities. Activities originally located at the site of EBR-1 gradually migrated to the new complex.

Reactor development depended partly upon tests in "critical assemblies," which are low power or zero power reactors (ZPRs) that allow the chain reaction to occur without a significant accumulation of heat or hazard. Using zero power reactors, experiments were conducted with various configurations of fuel to help test critical size, operating, and control features of a new or proposed reactor design.[34] ZPR-III was built near EBR-1 in 1955 to test core designs for EBR-II. It also tested designs for EBR-I's MARK-III core and for the Enrico Fermi Reactor.[35]

ZPR-III's critical assembly consisted of two tables mounted on a platform, one table movable, the other fixed. Drawers or trays for fissionable materials allowed the reactor to be loaded manually with different fuel configurations. The reactor was brought to criticality by moving the two halves together.[36]

Argonne eventually built two additional critical assemblies at its Illinois site to ease the demand on ZPR-III, but ZPR-III remained in operation until 1970 when it was replaced by the Zero Power Plutonium Reactor (ZPPR) a

[33] Loftness, *Nuclear Power Plants*, p. 339; Kendall & Wang, p. 7; "EBR-II since 1964," unpublished ms., historical files, INEEL Cultural Resources Office.

[34] ZPR-I, designed and built by Argonne in 1950, provided basic physics studies for the Navy's S1W submarine prototype reactor. ZPR-II was built to help test reactor designs for Du Pont's proposed reactor at Savannah River, South Carolina in 1951.

[35] Holl, *Argonne*, p. 149.

[36] J.K. Long et al, *Hazard Evaluation Report on the Fast Reactor Zero Power Experiment (ZPR-III)* (ANL Report, October 1969), p. 11-17.

larger, more versatile critical assembly at the Argonne-West site near EBR-II. In 1975, the ZPR-III critical assembly was decontaminated, dismantled, and moved to the EBR-I building for display. The ZPR-III containment building was decontaminated and dismantled.

Argonne Fast Source Reactor (AFSR). The AFSR, a low power, fast spectrum reactor, achieved criticality October 29, 1959. Associated with instrumentation tests for EBR-II, AFSR was originally located in a metal building southeast of ZPR-III. In 1965, AFSR was moved to the new Zero Power Plutonium Reactor Facility at Argonne-West, where it was used for instrumentation and operation tests until the late 1970s.[37]

Transient Reactor Test Facility (TREAT). In 1958, construction began on the Transient Reactor Test Facility (TREAT). A project of Argonne's Fast Reactor Safety Program, TREAT had a similar purpose as the BORAX tests, but for breeder-type reactors. TREAT was designed to test the behavior of various fuels and structural materials in breeder reactors under extreme or "transient" conditions.

The Teller Construction Company of Portland, Oregon, built the TREAT reactor and control buildings. Located just less than a mile northwest of EBR-II, it is built of aluminum-sided steel with a high bay and service wing. The reactor and associated instrument and utility areas are on the main floor. The basement is an equipment storage area and also contains the subreactor room, where control rod drive mechanisms are located. The control building, located approximately a half mile northwest of EBR-II, is a one-story concrete block structure. In 1982, the building was enlarged to accommodate larger reactor components and fuel elements.[38]

TREAT performed safety tests on samples of nuclear fuel. The reactor was graphite-moderated and air-cooled, using uranium oxide fuel. The reactor was designed to allow simulations of severe accidents, including meltdown or fuel element vaporization, without damage to the reactor. Slots

[37] Personal communication from Richard Lindsay, September 12, 1997; *Thumbnail Sketch* 1965; Harry Lawroski, "Zero Power Plutonium Reactor Facility," *Nuclear News* (February 1968), p. 47. See also Appendix A in *Proving the Principle* for estimated dates of operation of AFSR, p. 260.

[38] G.A. Freund et al, *Design Summary Report on the Transient Reactor Test Facility (TREAT)* (Argonne National Laboratory, June 1960, ANL-6034).

through the core allowed for a camera to record events taking place in the test hole during the excursion. Beginning in 1960, tests of fuel element designs for EBR-II were run in TREAT.[39]

Experimental Breeder Reactor II (EBR-II). After EBR-I had validated the idea that a breeder reactor could produce nuclear fuel, Argonne developed a design proposal for a second breeder reactor, EBR-II. EBR-II would serve as a prototype for commercial breeder reactors, but it was also designed to test and develop fuel reprocessing systems. EBR-II had a notable new feature: the reactor was submerged in a pool of sodium during operation.

Next door was a fuel reprocessing plant, at which spent reactor fuel would be removed from the reactor, sent through the reprocessing cycle, and returned to the reactor. Construction of the basic components of the EBR-II began in 1958 and the reactor was completed at Argonne-West in 1961. The architect/engineer for the project was the H.K. Ferguson Company of Cleveland, Ohio.[40]

The EBR-II complex includes four closely related facilities: reactor, power plant, sodium-boiler plant, and the Fuel Cycle Facility. The reactor building is a dome-shaped structure of one-inch-thick stainless steel, identified as "a gas tight containment shell" built to withstand an explosion the equivalent of 300 pounds of dynamite. The building houses the reactor facility, the primary sodium cooling system, and support systems. Because of the potential danger of explosion when sodium and water mix, there is no water system in the reactor plant.

Early in 1962, before the sodium coolant was added to the system, the reactor was brought to "dry criticality," and a number of tests were run at low power to provide comparison data for later experiments with the coolant present. Following the dry critical tests, the sodium coolant was added to the system in 1963. EBR-II achieved "wet" criticality in November 1963. The reactor operated at less-than-full power until 1969. Its spent fuel was reprocessed for the first time in 1964. EBR-II produced electricity for the first time in 1964. The reactor produced all of the power used at ANL-West and had power left over, so it supplied the NRTS as well. Argonne-West was able to "sell" power to Idaho Power, saving the AEC more than a million dollars each year.

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[39] Stacy, *Proving the Principle*, p. 136.
[40] *Frontiers*, p. 16; "EBR-II since 1964."

EBR-II's original design objectives -- to demonstrate the feasibility of a central-station fast breeder reactor and on-site fuel reprocessing -- were met by 1965. In a new phase of experimentation, the reactor was used as an irradiation facility to produce study samples for use in design of new reactors. Thousands of fuel elements, reactor components, and other reactor materials were irradiated and tested in EBR-II.

Zero Power Plutonium Reactor (ZPPR). In 1965 Argonne requested funding for the Zero Power Plutonium Reactor (ZPPR), a facility for testing fast reactor plutonium cores. The design of ZPPR allowed testing large core volumes (up to 5,000 liters), much larger than the facility at ZPR-III. The $3 million dollar request was granted and in August 1966, construction of the facility began. The reactor and ancillary systems were designed by Argonne, the structure was designed and built by Mason-Hanger Silas-Mason Company.[41]

The ZPPR facility consists of an earth and gravel containment mound and a support building. The support building houses the control room, staff offices, and the Argonne Fast Source Reactor. The ZPPR, a split table critical assembly similar to ZPR-III, but much larger, is housed within the containment mound. The 2,000-square-foot roof of the cell is a sand-and-gravel filter which varies from 16 to 21 feet in depth. A bank of 28 HEPA (high efficiency particulate air) filters backs up the sand-and-gravel roof to prevent the escape of airborne particles. Inside the mound, the reactor assembly was originally 10 feet x 10 feet x 8 feet, but was later expanded to 14 feet x 14 feet x 10 feet.

The work of the ZPPR was to carry out safety tests of reactor cores for fast breeder reactors. Some of the work that had been conducted in earlier, smaller critical assemblies was confirmed with additional testing in the ZPPR.[42]

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[41] Holl, *Argonne*, p. 269, mentions that ZPPR was the forty-sixth reactor built at the NRTS and was one of twenty-two in operation in 1969.

[42] Lawroski, "Zero Power Plutonium Reactor Facility," *Nuclear News* (Feb 1968); "Zero Power -- But Large Purpose," *Nuclear News* (January 1970; "ZPPR -- Zero Power Plutonium Reactor," Argonne National Lab brochure, no date; "Contributions of the Zero Power Plutonium Reactor (ZPPR) to the LMFBR Program," anon, no date.

Fuel Cycle Facility (FCF)

EBR-II was the first nuclear reactor with on-site fuel reprocessing incorporated into its design. The exterior of the building is concrete block and steel. Inside are two hot cells where the fuel elements from EBR-II were disassembled, reprocessed, and reassembled for use in the reactor.

The fuel elements were highly radioactive, so all work was done by remote control. Operating personnel worked behind heavy shielding. The hot cell walls were of concrete five feet thick. Materials were handled with bridge cranes, mechanical manipulators, and master-slave manipulators. One hot cell was doughnut-shaped and contained argon gas instead of air. This shape allowed workers access to the cell from work stations around the perimeter of the cell or from the center. The argon atmosphere was necessary to avoid problems when sodium or other reactive elements were present in the fuel elements. The atmosphere of the second, rectangular cell, was air. In the original facility, the argon cell was used to disassemble fuel elements, the air cell, to fabricate the recycled elements.[43]

Argonne-West and the Breeder Concept 1965-1970

Argonne National Laboratory's national role in reactor development shifted its emphasis in the 1960s, and the shift affected ANL-West. By 1960, fully half of ANL's budget and staff were devoted to reactor development. ANL expected to work on the fledgling breeder reactor program throughout the 1960s, or "a full ten years," as the AEC told the Joint Committee on Atomic Energy in 1960. The optimistic projections were that the breeder concept could create as much fuel as its original supply in five to ten years of operation. (It takes time for the new fuel to accumulate in the blankets surrounding the reactor core.) EBR-II and its Fuel Cycle Facility were operating in 1964, putting the projections to the test.

ANL had several proposals for development of reactor concepts other than the breeder and sought AEC funding to pursue them, but change was in the air. In 1965, with the appointment of Milton Shaw as the AEC's director of reactor development, the AEC decided to adopt the Liquid Metal Fast Breeder Reactor (LMFBR) as its top priority for commercial reactor development. The LMFBR was to be a demonstration

[43] D.C. Hesson, et al., ANL-6605; ANL-West brochure, "Hot Fuel Examination Facility," 1974).

reactor, operated on a larger scale than reactors operated up to that time. ANL was obliged to focus exclusively on the LMFBR. "Scaling up" the technology of EBR-II for commercial operation brought new problems of design, engineering, and safety controls. In 1971 President Richard Nixon confirmed the AEC's direction and called for construction of a commercial demonstration Liquid Metal Breeder Reactor by 1980.[44]

EBR-II and the ZPPR became the centers for LMFBR research. EBR-II, which by then had met its original objective of demonstrating the feasibility of a central-station breeder reactor and an on-site fuel reprocessing system auxiliary to it, became an irradiation facility, used to test fuels and materials. It produced study samples used in the design of new reactors. EBR-II irradiated thousands of fuel elements, reactor components, and other materials. The ZPPR, the largest critical assembly facility in the world, helped develop and test core mock-ups for commercial breeders. Information derived from the testing conducted in EBR-II and ZPPR provided the basis for design of the Fast Flux Test Facility (FFTF), the next step on the ladder to a demonstrator for a commercial LMFBR.[45]

The LMFBR program led to a reorganization of ANL's reactor development staff, construction of new facilities, and funneling of funds into the LMFBR program. Argonne-West grew substantially, and by 1967, the facility employed 275 people.[46]

Fuel Cycle Facility Modified as Hot Fuel Examination Facility

Argonne renamed its Fuel Cycle Facility several times as its mission shifted over the years. By 1968 the original studies planned for the facility had been successfully completed. More than 400 fuel sub-assemblies, containing

[44] Holl, *Argonne*, p. 230-235, 265-270, 272; "The Future Role of the Atomic Energy Commission Laboratories, a Report to the Joint Committee on Atomic Energy," (Washington: Atomic Energy Commission, January 1960), Vol. 1, Analysis and Conclusions, Section five, p. 80; Vol. 2, Supplementary Materials, p. 21.

[45] Glenn T. Seaborg and Justin L. Bloom, "Fast Breeder Reactors," (*Scientific American*, Vol. 223, No. 5), p. 19-20.

[46] Holl, *Argonne*, p. 273-277; "Employee Distribution by Work Location and Residence," February 1967, in vertical file, subject: Idaho National Engineering Laboratory, Idaho State Historical Society, Library and Archives, Boise.

more than 35,000 individual fuel elements, had been prepared for EBR-II.

The FCF was modified, renamed the Hot Fuel Examination Facility (HFEF), and dedicated by Idaho Congressman Orval Hansen on July 5, 1972. The HFEF was a hot cell capable of examining large irradiated specimens, part of the research for the Liquid Metal Fast Breeder Reactor program. The HFEF contained two shielded cells, one with an air atmosphere, and one with an argon atmosphere for reprocessing fuel elements. The walls of the cells are four feet thick, and the cells are 70 feet long, 33 feet high, and 30 feet wide. Work in the HFEF was done entirely by remote control, using master-slave manipulators and other automated or semi-automated equipment. Maintenance of the equipment is also remote-controlled and the design has been successful for more than twenty years.

Specimens brought to the HFEF were examined using either non-destructive or destructive techniques. If a specimen was to be returned for further testing, non-destructive examination such as photography, weighing, measuring, and gamma-ray spectroscopy recorded information for comparison after further testing. When a specimen arrived for destructive, or final, examination, samples were cut and prepared for a smaller HFEF hot cell or sent to the Analytical Laboratory.[47]

Expansion of the facility in 1975 brought another name change. The FCF was modified and its name changed to Hot Fuel Examination Facility-North (HFEF-N) in 1975 when the Hot Fuel Examination Facility-South was built. HFEF-N handled and examined irradiated specimens from EBR-II, TREAT, and other facilities.[48]

Argonne-West Significance

The cluster of reactors and support facilities at ANL-West have played a historically significant role in the history of nuclear reactor research in the United States.

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[47] "Fuel," *Nuclear News* (August 1972); ANL brochure "Hot Fuel Examination Facility," 1974; "Hot Fuel Examination Facility (HFEF)," ANL web site, June, 1997.

[48] When the Integral Fast Reactor (IFR) program took shape in the 1980s, HFEF-N was modified and renamed Fuel Cycle Facility. In 1994, the facility's name became Fuel Conditioning Facility, its mission to treat spent EBR-II fuel prior to planned disposal at a geologic waste repository.

Argonne National Laboratory was the country's first national laboratory; its Idaho Division was an integral part of its operation. Argonne was a leader and innovator in the AEC's breeder reactor development program.

The silver containment dome of EBR-II dominates the ANL-West complex. The reactor produced electrical power for ANL-West for thirty years, demonstrating the feasibility of a liquid metal reactor as a central power plant. Power production was so successful that EBR-II became the first co-generator in the State of Idaho. Also, it was the first reactor in the country to employ on-site fuel reprocessing, a function that operated successfully for six years of operation at the FCF.

Argonne's BORAX reactors provided the basic information leading to the design and construction of the Experimental Boiling Water Reactor (EBWR), the country's first nuclear power production pilot plant. BORAX-I proved that under extreme conditions the boiling water would shut the reactor down before heat could melt the fuel plates. BORAX-III was the first nuclear reactor to provide electricity to an American town (Arco, Idaho). The BORAX experiments laid the groundwork for SPERT, the next series of BWR safety tests. Private industry moved ahead with construction of the Vallecitos Boiling Water Reactor (California, 1957); the Bodega Bay Reactor (California, 1964), and the Pathfinder Reactor (North Dakota, 1964), all building on the experience and data gathered in the BORAX experiments. In short, the BORAX tests were a necessary precursor to the establishment of a commercial nuclear power industry that could operate within known safety parameters. All of the buildings associated with BORAX experiments have been demolished.

EBR-I has a unique historical importance. It was the first reactor built at the newly established NRTS. By the time it was decommissioned in 1964, the small reactor had been the first nuclear reactor in the world to produce usable electrical power, the first to employ a liquid metal as a coolant, the first to produce more fuel than it consumed, the first power-producing reactor to use plutonium fuel, and the first to experience a meltdown of the core. EBR-I provided basic information about nuclear reactors and power production.

As noted earlier, the National Park Service designated EBR-1 as a National Historic Landmark in August 1966 in ceremonies that included President Lyndon B. Johnson and AEC Chairman Glenn T. Seaborg. EBR-I was placed on the National Register of Historic Places in 1975, recognized as a

National Historic Engineering Landmark by the American Society of Mechanical Engineers in 1979, and named a Historic Landmark by the American Nuclear Society in 1994. The only original buildings remaining at the EBR-I site are the reactor building and the guardhouse.

SubTheme: *Reactor Testing, Experimentation, and Development*
INEEL Area: Test Reactor Area

Establishment of the Test Reactor Area: 1944-1954

After World War II, nuclear scientists hoped to apply nuclear knowledge for peaceful purposes. They understood how to apply a chain reaction to an explosive weapon, but very little about the best way to design reactors and reactor fuel for electrical power generation, propulsion, or other useful purposes. The list of unknowns was exceedingly long.

Even though physicists could design reactors that would generate enough heat to produce steam and generate electricity, engineers had yet to perfect the pipes, valves, fittings, and instruments that would keep the coolant moving, exchange its heat, and maintain the fuel at a constant and safe temperature. The limiting factor in the size or power level of a nuclear reactor is the ability of the coolant to carry away heat. [49]

At that time, chemists and engineers did not know much about how various materials would react in a nuclear environment. They didn't know the best materials to use for power reactors. They didn't know if their computations predicting how something would work were accurate. They didn't know how long metal, rubber, glass, and other fabrication materials would last under the constant bombardment of radiation. They didn't know how long a fuel element itself would last under the impact of radiation. Would a material react differently depending on whether the neutron was fast or slow? How? Would the fuel element change shape or lose strength? How? Bow inward? Bow outward? Crumble? Crack?

[49] Samuel Glasstone, *Sourcebook on Atomic Energy, 3rd edition* (Princeton, N.J.: D. Van Norstrand Company, Inc., 1967), p. 562-566.

They didn't know how certain materials would perform as absorbers or reflectors of neutrons. They didn't know how serious a problem it might be if some materials had impurities in their manufacture or were of uneven quality. They didn't know the best shape for the fuel -- rods? plates? curved? straight? They didn't know the best material to clad the fuel and hold it in position in the reactor core. For coolant piping, they didn't know what alloys of aluminum and steel would resist the corrosion caused by fission particles and extremely high temperatures. Of all the elements in the periodic table, they knew "cross sections" for only a few of them. (A cross section is the probability that neutrons at a given speed and temperature would strike the element's atoms.) Indeed, they didn't even know what materials would absorb neutrons or scatter them. Yet this knowledge was essential to designing reactors.[50]

In addition to everything else they didn't know, they had few safety procedures, standard practices, or efficient operating routines. Until they answered all these questions and hundreds more like them, nuclear scientists could not fulfill their hopes for the safe and peaceful use of atomic energy.

A Materials Testing Reactor

The scientists needed a reactor that could function as a kind of "mother reactor" to facilitate the design of other reactors. They needed to research how different temperature, pressure, and coolant conditions would affect various kinds of fuel assemblies. The reactor would be designed explicitly to test materials by exposing them to a high flow (flux) of neutrons and gamma radiation. In addition to solving these "urgent and practical" problems, they needed a reactor that could produce radioactive isotopes in sufficient quantity for medical treatment and experiments.[51]

Scientists needed to accumulate information quickly, considering the AEC's interest in developing the use of nuclear energy for power generation. A testing reactor could subject a material to the equivalent of months or years of radiation exposure in a much shorter period of time, simulating the expected period of time the material might be exposed to radiation in a power reactor.

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[50] *1965 Thumbnail Sketch*, p. 16.

[51] Phillips Petroleum, *The Materials Testing Reactor* (New York: United Nations, a reprint from Chapter 3, *Research Reactors*, presented to delegates at the International Conference on Peaceful Uses of the Atom, August 1955), p. 160-163. Hereafter referred to as *The MTR*.

The Progress of the MTR

As early as 1944, scientists at the Clinton Laboratory at Oak Ridge began designing what they called a "high flux" or "reactor development reactor," the Materials Testing Reactor, or simply the MTR. Just to design it required experimentation, and the Clinton Lab built small low-power assemblies to conduct such experiments.

In 1946 the Clinton Lab proposed that the AEC build a test reactor and a companion chemical processing plant to recover uranium from the reactor's spent fuel. The AEC agreed and assigned the Kellex Corporation to design it. By 1947, the project "was well advanced."[52] Naturally, the scientists at Oak Ridge expected that this reactor would be built there. But the AEC decided in 1948 to centralize its reactor development program at Argonne National Laboratory near Chicago and build it there. Overcoming intense disappointment ("[Argonne] stole all our reactors," was the bitter sentiment),[53] they cooperated with a five-member steering committee whose task it was to manage the final design and construction of the MTR.[54]

In the end, Argonne did not house the MTR either. The AEC's Reactor Safeguards Committee decided that the proposed power level of 30 megawatts was too high to risk operating near the four million people living in the Chicago area. Argonne's director, Walter Zinn, felt that the proposed chemical plant ought not to be near such dense population either. The MTR and the Idaho Chemical Processing Plant (ICPP) became two of the first four projects built at the new NRTS in Idaho.[55]

Because the Idaho site was not yet organized, the steering committee completed the design of the reactor and its associated support facilities, created a site plan, approved construction drawings, and began procuring materials and supplies. Blaw-Knox

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[52] John R. Buck and Carl F. Leyse, eds., *The Materials Testing Reactor Project Handbook* (Lemont, Illinois, and Oak Ridge, Tennessee: Argonne National Laboratory and Oak Ridge National Laboratory, 1951), p. 37. Hereafter referred to as *MTR Handbook*.

[53] *Atomic Shield*, p. 126. The other Clinton Laboratory reactor to be relocated was a Navy submarine reactor.

[54] Its members were S. McLain, chairman; M.M. Mann, ORNL; J.R. Huffman, ANL; W.H. Zinn, ANL; A.M. Weinberg, ORNL. *MTR Handbook*, p. 28.

[55] See *Atomic Shield*, p. 185.

was chosen the architect/engineer in July 1949, and preliminary plans were ready a few months later.[56]

While Blaw-Knox was at work, Kellex constructed a full-scale mock-up of the reactor at Oak Ridge. Its main purpose was to perfect the hydraulic performance of coolant and air circulation systems without the reactor producing neutrons. After initial simulations, the mockup operated on real fuel and ran as a low-power reactor, going critical for the first time on February 4, 1950.[57]

That same month, the AEC chose the Fluor Corporation to construct the MTR complex in Idaho. Fluor broke ground in May, and in July the AEC's Idaho Operations Office took the project over from the steering committee.[58] Construction proceeded somewhat unevenly, sometimes getting ahead of blueprints. Progress was interrupted further by an unusually cold winter in 1950-51.[59]

Siting the MTR

The AEC Safeguards Committee required that two concentric zones surround any reactor site. The near zone would be a controlled-access area where an accident could pose severe danger. The radius of this area was determined by a formula based on the reactor's power level. The second zone would be a "hazard area" to be determined by a combination of reactor type, meteorology, hydrology, and seismology. Danger within this zone would be much smaller; nevertheless, it should contain only a limited population.

In addition, an informal practice appears to have evolved during the Manhattan Project of siting reactors no closer than five miles from one another when this was feasible. John Horan, who arrived at the NRTS in 1952 and later served as director of Health Physics, said in an interview that this practice may explain why the MTR was located about five miles from the CFA and why the Navy's propulsion reactor was subsequently located five miles beyond the MTR.[60]

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[56] *MTR Handbook*, p. 38.

[57] *The MTR*, p. 210. The MTR was a tank reactor with a steel lid over the top. It was water-cooled, beryllium reflected, and used aluminum-clad fuel plates.

[58] *MTR Handbook*, p. 43.

[59] *Atomic Shield*, p. 496.

[60] John Horan, in telephone interview with Susan Stacy, July

The civil engineers surveying for a specific location for the MTR wanted to build on solid lava rock. They noticed that as the distance increased from the gravel creekbed of the Big Lost River, the depth to bedrock decreased. Therefore, knowing the depth of the MTR basement, they simply placed the building at a point where the gravel overburden matched the basement depth. They cleared the gravel and anchored the building to the lava. Horan said these engineers "bragged for years" about how this strategy saved the considerable costs of building footings or blasting through lava rock. They employed the same procedure in siting the ICPP and the Navy's first reactor. At the time, less was understood than today about the boundaries of the river's flood plain, so the legacy of the siting strategy is a location that requires vigilance with respect to potential floods.[61]

The MTR steering committee liked the terrain around the selected site. Because one of the proposed experiments would project a neutron beam a quarter of a mile from the MTR, the committee wanted a site that was flat for at least that distance around the reactor. The site also provided access to water and had natural drainage for retention basins. Finally, a convenient site for the Chem Plant -- at the right elevation above bedrock -- was available about one and a half miles away and would not be downwind of prevailing winds from the MTR.

The principle of isolation applied to all future NRTS reactor experiments (if not always at five-mile increments), so the NRTS's characteristic land-use pattern of widely distributed clusters of buildings established itself from the beginning. The MTR, the ICPP, the Navy propulsion project, and the Experimental Breeder Reactor (EBR-1) each settled in its own "desert island," connected to the CFA by roads and utility lines.

Designing the MTR Complex--Taking Account of its Natural Setting

Within the rectangular MTR complex, buildings and their future expansions were oriented with respect to predominant winds, which came from the southwest during the daytime. This dictated the location for the exhaust stack on the east side of the compound. And the stack had to be high. Contaminated air had to be discharged high enough to disperse and dilute over a large uninhabited area. For security reasons, it had no aircraft warning lights.[62]

29, 1997.

[61] John Horan, July 29, 1997.

[62] *MTR Reactor*, p. 352.

One of the major features of the MTR was its "canal," an underwater facility for storing spent fuel until it could be sent to the Chem Plant and processed to recover its uranium. The below-grade canal projected 87 1/2 feet from the east side of the main reactor building. The canal was built 25 feet longer than called for in the original plan because during 1951 the managers were not sure that the Chem Plant would be operational in time to take delivery of MTR's first several months' accumulation of spent fuel. The extra length would accommodate extra fuel.[63] The ceiling of the canal tunnel, made of reinforced concrete, was slightly below ground level. The road that passed over the canal was reinforced to support the heavy trucks and crane used to lift the transport casks. The unloading hatch was at an offset widened portion of the road located where traffic had the least impact on loading operations.

The MTR's auxiliary buildings were oriented to each other for the shortest feasible extensions of piping, air ducts, wiring, fencing, roads, and walkways.[64] The entire complex was surrounded by a barbed-wire perimeter fence with the parking lot outside. Just inside the fence was a 10-foot wide patrol road. The reactor building and other buildings containing radiation hazards were further fenced within an "exclusion" area.

Thus, by intentional design, the buildings in the most intimate association with reactor operations in the exclusion area were the reactor building, its laboratory wing, the storage canal, the hot cell building, plug storage building, process water building, fan house and stack. A 150,000 gallon water reservoir also was in the area.

On the upwind side were the pumps and wells, storage tanks, substation, demineralizing building, emergency diesel generator, steam plant, cooling tower, warehouses, administration and service building, and canteen. Downwind and outside the perimeter fence were the sewage plant and evaporation ponds.

The MTR Goes Critical

The Korean War began in June 1950. The AEC's peaceful intentions for the MTR had to yield to the demands of national defense. The MTR could help speed the development of plutonium-producing reactors for weapons and propulsion reactors for Navy submarines.[65] In fact, during 1950, the study groups working at

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[63] *MTR Handbook*, p. 287.

[64] *MTR Handbook*, p. 356.

[65] *Atomic Shield*, p. 419.

Argonne considered how the MTR could be modified to produce plutonium should this be necessary. The Chem Plant, originally intended to reprocess only MTR fuel, also was recruited for defense. Design changes enabled it to process U-235 fuel slugs used at Hanford's tritium-production reactors, Naval reactor fuel, and later the fuel for the Air Force's turbojet experiments.[66]

At the end of 1950, after considering 34 candidates, the AEC contracted with Phillips Petroleum Company to operate the MTR, partly because it wanted physicist Richard L. Doan, director of research at Phillips (and who had previously been loaned to the Manhattan Project) to be the manager. Doan brought with him 42 other Phillips specialists.[67] The group spent several months at Oak Ridge training in nuclear physics, health and safety, and reactor operation and management. There they practiced operating Oak Ridge's High Flux Training Facility, the new name for the MTR mock-up.

The MTR went critical for the first time on March 31, 1952, with Fred McMillan, the reactor manager, at the controls. Operators carefully increased its power, making adjustments as needed, until it reached its full power operation of 30,000 kilowatts. On August 5, 1952, the MTR opened for business as the first test reactor in the world designed to test components for future reactors.[68]

MTR Work

The MTR was an instant hit. Like Sun Valley, another Idaho landmark, the MTR became so essential and so famous that nuclear literature at the time often dropped references to its country and state. MTR test loops were busy irradiating proposed fuels for the Navy's *Nautilus* and other reactor prototypes, for the proposed nuclear-powered bomber, and for reactors at the AEC's Savannah River weapons plant. It developed non-destructive techniques for the Chem Plant to assay the uranium in fuel

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[66] *Atomic Shield,* p. 496, 499.

[67] *Atomic Shield,* p. 496. See also Phillips Petroleum, *Phillips, The First 66 Years* (Bartlesville, OK: PPCo, 1983), p. 140. Other Phillips employees who moved to Idaho with Doan were Alene Carter, fuel tester; Hugh Burton, physicist; Harry Markee, safety specialist; Ed Fast, physicist. See also Rich Bolton, "Fast Enters Retirement at same well-known pace," *INEL News* (Sept 7, 1993), p. 5.

[68] *Atomic Shield,* p. 515. See also "INEL Pioneers set high standards," *INEL News* (March 19, 1991), p. 4.

assemblies that were to be dissolved. It irradiated thousands of materials.[69]

One example will illustrate how the MTR was instrumental in the design of nearly every reactor later built in the country. Sylvania Electric Products Company wished to manufacture fuel slugs for the AEC. Using two different techniques, Sylvania fabricated eighteen fuel slugs made of natural uranium. MTR operators subjected them to prolonged high flux exposure -- and observed both types gradually change their shape and size, increasing in diameter and decreasing in length.[70] Findings such as these were of critical importance in safe reactor operations. If fuel slugs were spaced too close together in a reactor and expanded, they could choke off the flow of coolant, cause a hot spot, melt the fuel, damage the reactor, and cause a serious accident.

By the time the MTR shut down for the last time in 1970, it had performed more than 15,000 different irradiation experiments, and its operators had disseminated the findings to a large community of nuclear scientists.

The Test Reactor Mission Grows

As the steering committee had anticipated, the MTR site expanded. A Hot Cell Building (TRA-632) went into use in the summer of 1954. Here, operators, while shielded safely behind thick concrete walls and special viewing windows, could handle, photograph, mill, measure, and weigh radioactive samples using remotely operated manipulators.

The AEC authorized a Reactivity Measurement Facility (RMF) in February 1954. This was a small (very low power) reactor located in the east end of the MTR canal, where water was its moderator, reflector, and shield. It complemented the MTR in that it had a high sensitivity to subtle changes in reactivity, unlike the MTR. The author of the proposal suggested that the small facility would function as a "detector," whereas the large MTR functioned as a "source" of neutrons. The two functions could not be maximized in the same reactor. The RMF enabled studies of reactivity changes in hafnium, zirconium, and other fuel materials as a function of their total irradiation -- without having to transport the experiment to some other more distant

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[69] J.R. Huffman, *MTR Technical Quarterly Report, First Quarter 1954* (Idaho Falls: PPCo Report IDO-16181), p. 5-13.

[70] J.R. Huffman, *MTR Technical Quarterly Report, Second Quarter, 1954* (Idaho Falls: PPCo Report No. IDO-16191), p. 17; and Huffman's *Third Quarter 1954 Report*, PPCo No. IDO-209, p. 12.

facility on the NRTS site.[71]

Demand for space in the MTR grew to such an extent that merely expanding its adjunct facilities was not enough to satisfy it. By the end of 1954, the scientists were making preliminary calculations for a new, larger, more convenient, and higher power test reactor.

In 1954 the United States was entering a new phase of its atomic energy program. Congress passed a new Atomic Energy Act, superseding the old act of 1946. Due largely to the successful research program carried out at the MTR and other AEC facilities, the time had arrived for private enterprise to become more involved in the development of a nuclear power industry. Up to this point, private ownership of atomic facilities had been forbidden. The new law provided for private licensing of reactors and nuclear fuel. Further, it allowed industry scientists access to information that heretofore had been classified.[72]

TRA Programs Expand: 1955-1970

The pace of activity at the NRTS in general picked up markedly in 1955. National defense made continued demands on the MTR. The Korean War had ended, but the Cold War competition for weapons supremacy between the United States and the Soviet Union was an escalating pressure at the Test Reactor Area (TRA).

New activity centers had sprouted up at the NRTS. One was Test Area North, site of General Electric's turbojet experiments for the U.S. Air Force, where the first Heat Transfer Reactor Experiment went critical on November 4, 1955. Another was the SPERT program, a series of experiments begun in 1955 that examined the safety and stability of water moderated reactor systems when their power levels increased unexpectedly.

The MTR played a role in most of the new experiments. For SPERT I, for example, the Argonne experimenters predicted what would happen when power levels rose as high as 2400 megawatts. When the results of the actual test were other than expected, the

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[71] W.E. Nyer, et al. *Proposal for a Reactivity Measurement Facility at the MTR* (Idaho Falls: Phillips Petroleum Report No. ID)-16108), p. 6-8. Reactivity is a measure of the departure of a nuclear reactor from criticality. The measure is either positive or negative and indicates whether neutron density will rise or fall over time. An RMF is also called a "critical facility."

[72] Public Law 83-703 was enacted by the 83rd Congress, 2nd session, and signed into law by President Eisenhower August 30, 1954.

MTR helped determine why the calculated prediction was in poor agreement with that obtained in the experiment.[73]

To accommodate a growing demand for gamma irradiation experiments by commercial interests, the AEC's Idaho Operations Office designed a gamma irradiation facility (TRA-641). Because of the classified military work conducted at MTR, commercial scientists without security clearance could not be admitted to the MTR exclusion area. However, to provide them access to gamma radiation for tests, the Gamma Irradiation Facility was located outside the security fence.

The Gamma Facility opened in 1955. The facility took advantage of the MTR's spent fuel, a valuable research asset. After removal from the MTR core, it radiated gamma rays, a penetrating form of energy (and hazardous to human health.) Very active when first removed from the reactor, the gamma source would gradually decay. An experimenter could specify the degree of "freshness" required for a given test.[74]

Fuel was transported to the facility from the MTR in 26,000-pound fuel-element carriers made of lead, steel, concrete, and water. Once the fuel was in the facility's 6-foot wide storage canal and shielded by 16 feet of water, operators maneuvered the elements into cadmium boxes and positioned them at safe distances from the adjacent elements (to prevent an accidental chain reaction). Packages containing the materials to be tested were wrapped in water-tight containers and dipped into the canal at a selected distance from the fuel element. Depending on the length of time the material was to be exposed, packaging could be a plastic bag, a can, or a special container with a corrosion-resistant coating.

Experimenters paid non-profit rates (40 cents per million roentgens plus shipping; $10 minimum charge) to be scheduled on a first-come, first-served basis. They subjected nearly everything imaginable to gamma radiation -- potatoes, meat, plastics, heat-sensitive pharmaceuticals, diamonds -- anything for which there was a hope that irradiation would improve it, make it last longer, or increase its value. At any given time, the canal contained forty to fifty fuel elements.[75]

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[73] IDO-16259, p. 13.

[74] J.R. Huffman, *MTR Technical Branch Quarterly Report for First Quarter, 1955* (Idaho Falls: PPCo Report No. IDO-16229), p. 24.

[75] *Gamma Irradiation Facility, A Fact Sheet*, no author, p. 3-5. Pamphlet found attached to the 1957 version of *Thumbnail Sketch*.

In September 1955, the MTR reached a milestone when Phillips increased the power level in the reactor to 40 megawatts. Higher levels permitted more rapid irradiation of materials and thus increased the speed at which an experiment could deliver results.[76]

Phillips' quarterly technical reports detail a constant barrage of research problems and questions. From the Chem Plant: Will it be safe to put 250 kilograms of two-percent enriched slugs into C Cell's 30-inch dissolver? From a reactor development program: Will these fuel pellets made of aluminum-uranium alloy melt under irradiation? From the medical community: Can thulium-170 be used as a source for radiography? Do impurities in the thulium produce undesirable effects? From the Bureau of Mines: Will neutron and gamma radiation improve the coking characteristics of Sewickly coal? From SPERT: What's the best way to design SPERT III so it will operate at temperatures of 650 degrees? From fuel manufacturers: Congress is allowing the U.S. to sell 20 percent enriched fuel to foreign interests. How will it perform in a high flux reactor?[77]

And, because the MTR itself was an experiment, Phillips conducted tests on how the reactor's own components were holding up. Had the fast flux of neutrons caused any structural weakness in the materials within the core area? Using its findings on this and other accumulated experience, Phillips designed the next test reactor.[78]

The Engineering Test Reactor (ETR)

By 1957, higher neutron fluxes than what the MTR could provide were in demand all over the country. Higher fluxes meant that an experiment could be carried out in a shorter period of time. Lower fluxes, such as those provided in the MTR low flux graphite zone, were no longer in demand except as a "mine" for isotope production.

In addition, test requirements were growing more sophisticated. Using MTR beam holes involved complicated and time-consuming handling problems. Also, in situations where it was important to have a uniform rate of flux, it was hard to supply this to the sample. Many experiments needed more room in

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[76] IDO-16254, p. 6.

[77] See series of Phillips Technical Branch quarterly reports for 1955 through 1957.

[78] IDO-16297, p. 5.

order to be in the proper test environment and not impact the MTR operation. Phillips designed the Engineering Test Reactor to solve these problems. It provided large spaces in the highest flux zone in the core. Further, the flux was uniform along the entire 36-inch length of the fuel elements.[79]

After the AEC approved Phillips' conceptual design, it hired Kaiser Engineers to design and build the ETR. Kaiser had General Electric design the reactor core and its controls. From design to completion, the project took two years. The reactor was a standard tank design except that its control rods were driven through the core from below the reactor, not from above. This left the area above the reactor available for experimentation.[80]

Siting the ETR

Phillips situated the airtight ETR building about 420 feet south of the MTR (center to center) so that it could share the MTR's auxiliary facilities while positioning its cooling towers to the east. Here it would be convenient to the MTR's operational centers (such as the Hot Cell, Hot Plug Storage, and Reactor Services Building) and yet be free of the facilities and services associated solely with MTR operations. Many of the shared facilities -- raw water, electrical and steam distribution, fuel oil, sewer, standby power, waste disposal -- then were extended or enlarged. This arrangement still left space available for even further expansion of both ETR and MTR facilities.[81]

The single most critical design driver for the reactor building was the size of the reactor vessel. When that was determined in October 1955, the rest of the planning continued. (The vessel is 35 feet long, with a diameter ranging between twelve and eight feet. It had to withstand a pressure of 250 pounds per square inch at a temperature of 200 degrees F.) Building height had to account for the bridge crane that would

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[79] "Test Reactors--The Larger View," *Nucleonics* (March 1957), p. 55.

[80] Philip D. Bush, "ETR: More Space for Radiation Tests," *Nucleonics* (March 1957), p. 41-42. The extra depth required for the control rods meant that a portion of the foundation had to be blasted through lava rock. See also R.M. Jones, *An Engineering Test Reactor for the MTR Site (A Preliminary Study)* (Idaho Falls: Phillips Petroleum Report No. IDO-16197, 1954), p. 7.

[81] R.M. Jones, *An Engineering Test Reactor for the MTR Site (A Preliminary Study* (Idaho Falls: Phillips Petroleum Report No. IDO-16197, 1954), p. 7.

manipulate and place the vessel.[82]

Other design features of the complex were based on experience with the MTR. The MTR had provided insufficient office space for both visitors and resident technical personnel. Desks cluttered the reactor floor, balconies, and any free space near the experimental equipment. To address this, three-level "lean-to" extensions were added to the ETR building on the east and west sides to prevent similar frustrations. Partitioning of the reactor floor was avoided, leaving the entire area free for experimental equipment.[83]

Because the reactor would operate at a power level of 175 megawatts, it generated considerably more heat than the MTR. The primary coolant loop contained demineralized water. To keep it from boiling, it had to be kept pressurized. Pressure was maintained by pumping the water through the core and withdrawing it at a rate that would maintain the desired pressure. A secondary loop discharged the heat to the atmosphere. Exhaust gases were filtered and vented to a new stack. Because the coolant accumulated radionuclides, the pipes between the reactor building and the heat exchanger building were shrouded with concrete shielding.

ETR Work

The typical life of a fuel element was eighteen days, in which time about 27 percent of the uranium fissioned. Like the MTR, the ETR required a water-filled canal where spent fuel elements could cool down before transport elsewhere.[84] ETR operators, like their colleagues at MTR, where the cycle also was 18 days, lived a cyclical lifestyle, taking three days to unload and refuel the reactor. Using remote manipulators, an operator could lift a fuel assembly part way up the side of the tank, tilt it, and slide it through an opening and down a chute. The element "flopped" into the 18-foot deep canal, where technicians used grappling poles to guide the element to a resting place on a rack. Here, the fuel sat for several months to cool off, its radioactive constituents continuing to decay. With the help of a 30-ton crane, it would be maneuvered into a special shielded

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82 R.H. Dempsey, "ETR: Core and Facilities," *Nucleonics* (March 1957), p. 54; and Kaiser Engineers, *Engineering Test Reactor Project, Part I*

83 R.M. Jones, *An Engineering Test Reactor for the MTR Site (A Preliminary Study)* (Idaho Falls: Phillips Petroleum Report No. IDO-16197, 1954).

84 Bush, p. 41-56. See also *1965 Thumbnail Sketch*, p. 15.

transport cask, called a "coffin," and shipped down the road to the Gamma Facility or the Chem Plant to recover the valuable U-235 still remaining in the fuel element.[85]

The ETR went critical for the first time at its full power level of 175 megawatts on April 19, 1957; the ETR Critical Facility (ETRC), on May 20, 1957.[86] This low-power reactor did the same for ETR as the MTR's Critical Facility. In order to run the reactor safely and efficiently, operators had to know how the experiments would affect power distribution, whether the reactivity effects of experiments would impact the reactor or generate potential hazards. This information had to be available before each new cycle was begun. It used fuel and control rods like the ETR's and had the same type of beryllium-beryllium oxide reflector.[87]

The ETR mission was to evaluate proposed reactor fuels, coolants, and moderators. It was designed especially to simulate environments like those expected in civilian nuclear power reactors. ETR had more test space and more flexibility than the MTR. Over 20 percent of the head volume over the vessel was filled with test voids -- like a "large cake of swiss cheese," as one writer put it.[88]

During its lifetime, the ETR had less on-stream time than the MTR because its experiments were more elaborate and required more time to plan, pre-test, and install. They were more expensive, too. Various test "sponsors" invested over $17 million to adapt 18 of the test loops for their experiments.[89] Fabricating the tests required the services of welders, pipe fitters, heavy equipment operators, carpenters, mechanics, and many other specialists. These craft specialties explain the numerous shop buildings erected at the TRA complex and at the CFA to support these activities.

Demand for test space kept growing, calling for more than the MTR and ETR could supply. Use of space was prioritized and allocated by the Washington Irradiation Board. Military and AEC

[85] R.H. Dempsey, "ETR: Core and Facilities," *Nucleonics* (March 1957), p. 54.

[86] R.L. Doan, "MTR-ETR Operating Experience," *Nuclear Science and Engineering* (January 1962), p. 23.

[87] *1965 Thumbnail Sketch*, p. 15.

[88] Bush, p. 43.

[89] Doan, p. 24.

priorities came first. After that, the rule was "first come, first served." If private test space were available elsewhere, the Board rejected commercial requests for irradiations in the ETR.[90] Nevertheless, ETR customers included research and educational institutions, and the civilian power industry.

Advance Test Reactor (ATR)

Even before the ETR went critical for the first time, the AEC had been requesting studies for an "advanced" general purpose test reactor, one that would supply the AEC's needs long into the future.[91] In addition, high demand from the Naval Reactors Program continued to press the capacity of the MTR and ETR test reactors. A new reactor, while planned for multiple purposes, would specifically meet the long term needs of the Naval Reactors program, with many of its test loops reserved for Navy work.[92]

Phillips prepared the conceptual design, combining its MTR and ETR operating experience with ideas from physicists at laboratories all over the country. One of the "advanced" features of the ATR was its ability to test several samples in the reactor at the same time, but exposing each one to different absolute flux levels. And flux levels were intense. The MTR designers had been reluctant to place test materials within the reactor core; but the ETR had a fuel grid that permitted just that. The ATR went further. With its "serpentine" or clover-leaf arrangement of fuel, a test material could receive a level of exposure in a few weeks, instead of years of equivalent exposure in the ETR. To accommodate varying power levels in its seven test loops, the ATR required an extremely sophisticated control system. A built-in computer -- an innovation at TRA -- reported continuously on reactor conditions.[93]

The AEC announced in October 1960 that Ebasco Services would be the architect/engineer, with Babcock & Wilcox preparing the nuclear core of the reactor. The reactor would operate at 250 megawatts, nearly 1.5 times the power level of the ETR -- and the

[90] Doan, p. 32. See also *1965 Thumbnail Sketch*, p. 13.

[91] See J.R. Huffman, W.P. Connor, G.H. Hanson, "Advanced Testing Reactors," (Idaho Falls: Phillips Petroleum Company Report No. IDO-16353, May 28, 1956.)

[92] D.R. deBoisblank, "The Advanced Test Reactor--ATR Final Conceptual Design," (Idaho Falls: Phillips Petroleum Company Report No. IDO-16667, 1961), p. 11-12.

[93] *Advanced Test Reactor*, pamphlet, undated (Idaho Falls: Idaho Nuclear Corporation), p. 3.

highest operating power level of any test reactor in the world. In addition to the special Navy program loops, it would have a gas test loop, a pressurized water test loop, and sodium-cooled test loops for fast and thermal reactors. Although it considered other sites for the project, the AEC chose the NRTS for practical reasons: the Navy program already was established there; having the three test reactors operated as a single complex would be efficient and economical; Phillips was a highly competent operator; and the NRTS was the least limiting AEC site with respect to safety.[94]

Siting and Building the ATR

With Idaho Governor Robert Smylie attending the ground-breaking ceremony on November 6, 1961, the ATR became the largest single construction project ever undertaken in the state of Idaho, eclipsing the earlier record-holder, Mountain Home Air Force Base.[95] The Fluor Corporation built the project, situating the ATR building about 200 yards northwest of the MTR. A cooling tower, critical facility, metallurgical research facility, labs, and other structures supported the new reactor.[96]

The ATR complex opened up a new TRA quadrangle northwest of the MTR-ETR area. The site plan repeated earlier patterns of compact placement of support buildings around the reactor, although the large reactor building, with a first floor area of 27,000 square feet, enclosed several functions: the reactor and working area, the Advanced Test Reactor Critical Facility (to determine in advance the nuclear experiments to be programmed), decontamination room, office area, experimental labs, health physics labs, tool rooms, and heating/ventilating equipment. A common canal served for the critical facility reactor, for fuel element storage, for conducting irradiations, and for transferring fuel from one work area to another without using transport casks.[97]

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[94] Letter to Clinton P. Anderson, chairman JCAE from office of the General Manager, AEC. No date, 1960. Idaho Historical Society, US Senator Henry Dworshak Papers, Mss 84, Box 112, File "AEC-Miscellaneous."

[95] "Idaho Rites Start Record Atom Job," newsclip with no date, *Post-Register*, p. 1, 12. Found in Idaho Historical Society, Senator Henry Dworshak Papers, Mss 84, Box 124, File "AEC--Idaho Plant (1961)."

[96] AEC announcement, October 25, 1960; Idaho Historical Society, Senator Henry Dworshak Papers, Mss 84, Box 112, File "AEC Miscellaneous." See also *1965 Thumbnail Sketch*, p. 15-17.

[97] The ATR Critical Facility went critical for the first time

Other buildings in the complex included a shielded process water building immediately north of the reactor building with an enclosed driveway connecting it to the reactor building. This building contained the piping and controls for a heat exchanger, transferring heat from the primary to secondary coolant. A utility building containing diesel generators and demineralized water equipment was located east of the process water building. Laboratories and engineering space were housed in a one-story building east of the reactor.

After years of delay caused by the failure of heat exchangers, valves, emergency pumps, and instrumentation cables, Fluor completed the reactor in 1967. It began operating at zero power on July 2, 1967. On August 16, 1969, it operated at full power for the first time. Nuclear experiments began on Christmas Day. By this time, Phillips no longer was the TRA contractor; Idaho Nuclear Corporation had assumed control in 1966.[98] The ATR has continued routine operation since then.

ATR Work

The ATR routine was similar to that of the MTR and ETR. At the end of seventeen days operating at full power, about 15 percent of the U-235 in the core was consumed. The reactor shut down for refueling, to change experiments, and make other modifications. To conserve time during the shut-down interval, the crews of engineers, welders, electricians, and health physicists operated around the clock in three shifts.[99]

Compared to the long line of customers clamoring for the MTR and ETR in their early years, the clients of the ATR shrank to a small group. The major user was the Navy, which had grown its *Nautilus* submarine into a huge nuclear fleet consisting of submarines and surface ships in many classes and sizes. ATR analysis of Navy fuel led to continuous improvements in extending the operational life of a ship's fuel. The civilian power programs and the national space program also were looking to advance the science of fuel systems and materials. They, too, made use of ATR test loops.[100]

on May 19, 1964.

[98] "Advanced Test Reactor Now Running at Full Power," *Nuclear News* (October 1969), p. 17.

[99] *1965 Thumbnail Sketch*, p. 15.

[100] *1965 Thumbnail Sketch*, p. 15.

MTR Retires in 1970--Reluctantly

In 1968, the AEC announced it would shut down the MTR in 1970. In response, other interests tried to develop commercial possibilities, hoping to keep the venerable MTR operating. The State of Idaho had formed an Idaho Nuclear Energy Commission in 1967 to promote nuclear applications in agriculture, mining, lumbering, and other fields. In 1969 a Western Interstate Nuclear Compact formed to promote nuclear commerce and trade in all the western states. These two groups tried to continue the life of the MTR as a "Western Beam Research Reactor." The problem was funding.

The Associated Western Universities proposed that the AEC finance some fifty research projects at the MTR, but the AEC was unwilling or unable to fund the proposal. The National Science Foundation considered the MTR as a possible "National Neutron Center of Interdisciplinary Studies," but concluded in 1972 that high-flux neutron beam capability would be cheaper at its Brookhaven, New York, or Oak Ridge laboratories than at the MTR.[101] Efforts to find a private buyer or renter for the MTR also failed.

For a brief period in 1970, all three test reactors at TRA operated at the same time. The last MTR experiment was called the Phoenix, in which the reactor was loaded with plutonium fuel. The test verified that this particular mix of isotopes would create more fuel than it consumed -- thus vindicating its name "rising from the ashes." Officially, the MTR's last day of operation was April 23, 1970.

But later in the year, the State of Idaho appealed for two days of operation in order to irradiate samples of pheasant and other wildlife. The Idaho Department of Fish and Game had recently discovered mercury in pheasant flesh and needed information quickly as to the potential extent of this problem. At the time, some farmers used grain fungicides containing methyl mercury. If mercury poisoning were widespread, the Department of Fish and Game would have to cancel the forthcoming hunting season. The NRTS obliged the state and loaded up the reactor with about a thousand samples of fowl and fish from several locations, irradiating them for about two days in August 1970.[102] That was

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[101] "Annual Report of the Idaho Nuclear Energy Commission, Report No. 6, 1972," (Boise: INEC, 1973), p. 14-15.

[102] "INEL Programs set high safety standards," *INEL News* (March 19, 1993), p. 4. See also *Annual Report of the Idaho Nuclear Energy Commission, No. 4, 1970*, p. 6; Darrell W. Brock, "Application for Funding for a Proposed Study of Mercury Poisoning in Idaho," May 28, 1970, copy in Senator Len B. Jordan Papers,

the MTR's final service; it was decommissioned in 1974.

Significance of the MTR, ETR, and ATR

Because the MTR was the first multipurpose test reactor in the world, it moved the boundaries of nuclear knowledge constantly outward. Providing the world's most intense neutron flux available, the MTR performed its tests in relatively short times and produced radioisotopes of higher specific activity than any other reactor.

It accomplished its test mission safely. It logged 125,000 operating hours, sometimes with 600 samples loaded at a time. It conducted more than 19,000 irradiations in 800 different programs. The AEC had sponsored most of them, but many commercial clients had been served as well. In addition, MTR had accommodated ten major Air Force experiments, fifty major Navy experiments, and several for the Army.[103]

Among its peaceful services, the MTR had supplied hospitals with irradiated Cobalt-60 and other radionuclides, evaluated the economics of hydrazine rocket fuel, measured the properties of known trans-uranic elements and helped discover new ones. MTR spent fuel provided gamma radiation to countless samples of food -- testing the possibility that irradiation might extend the shelf life of food without refrigeration -- and thousands of other substances.

MTR was the first reactor ever to use Plutonium-239 fuel at power levels up to 30 megawatts, demonstrating that a reactor fueled with plutonium could be satisfactorily controlled.[104] Phillips physicist Deslonde deBoisblank announced this achievement at the Geneva Atoms for Peace Conference in 1958.[105]

In its early years, MTR experiments contributed to the design and improvement of all commercial pressurized water reactors in the United States and many beyond its borders. Later, it contributed to the Yankee and Dresden power reactors at Rowe, Massachusetts, and Morris, Illinois, respectively; to the organic reactor; to the liquid metal fuel reactor; and to the homogenous

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Boise State University, Box 174, File 32.

[103] *1961 Thumbnail Sketch*, p. 23-25; *1973 Thumbnail Sketch*, p. 7.

[104] *1959 Thumbnail Sketch*, p. 22.

[105] AEC Press release, September 11, 1958; IHS, Mss 84, Box 83, File "AEC--Idaho Plant."

fuel reactor.[106]

Behind the MTR were the people who managed, operated, maintained, and improved it. Quite simply, everything they did was new. The accomplishments of the pioneering machine were nothing less than the accomplishments of the human pioneers who devoted themselves to its success.

After all of the "firsts" accumulated by the MTR, the two reactors that followed it had a hard act to follow. Each, however, represented the most advanced designs in the world at the time for test reactors and were major landmarks in the history of test reactors. The ETR and ATR were significant and essential partners in the safe operation and success of the American nuclear fleet -- and in the development of the commercial power industry and the space program. In addition, they incorporated highly advanced and unique designs unlikely to have been replicated anywhere else in the world. When the fortunes of the commercial reactor industry began to decline in the 1970s, their role in scientific innovation also declined. Much of the ATR's work involved the analysis and improvement of performance rather than expanding the universe of knowledge.

The closure of the MTR -- and, most particularly, its failure to find either a commercial or institutional champion -- signaled the beginning of a different era in nuclear research at the NRTS. Until that time, NRTS research reactors had slaked an urgent thirst for nuclear knowledge. Its mission to "mother" other reactors had succeeded, but the nation was changing its mind about nuclear power. The role of nuclear research in the development of "atoms for peace" began what now appears to be a 26-year decline.

SubTheme: *Reactor Testing, Experimentation, and Development*
INEEL Area: Organic Moderated Reactor Experiment

The Organic Moderated Reactor Experiment (OMRE): 1957-1963

Among the many experimental reactor concepts that the AEC tested was a reactor that would use a liquid hydrocarbon as a coolant and a moderator. It contracted Atomics International -- which had conceived the concept -- to develop the reactor at the NRTS. From 1957 to 1963 the Organic Moderated Reactor Experiment (OMRE) was in operation. OMRE was notable as the first

[106] Dresden was the first large-scale privately owned boiling water nuclear power station to go into operation (in 1959) in the United States; Yankee soon followed as the first pressurized water power reactor (in 1960).

experimental reactor constructed at the NRTS with partial funding by private industry.[107]

Most reactor concepts at the time used water -- either light or heavy, pressurized or boiling -- as a coolant. During the late 1950s scientists began to consider materials other than water for use as coolants in reactors. Water has the disadvantage of becoming corrosive at the high temperatures to which it is subjected in the reactor. It was necessary to use stainless steel or zirconium alloys to clad the fuel elements over which the heat-removing water passed. The advantage of organic substances over water is their low vapor pressure and low corrosion effects. Initial studies and experiments at the MTR inspired scientists to try the concept of an organic fluid.[108]

The OMRE complex consisted of a 4,300 square-foot steel process and control building, a large airblast heat exchanger, a storage area, an auxiliary heat exchanger, a pipe gallery, several underground tanks, and extensive piping and electrical systems.[109] The complex was located east of the CFA (in the south central section of the NRTS) about halfway between the CFA and the Army Reactors Area.

The organic material used for OMRE was called Santo-wax-R, a mixture of terphenyl and diphenyl isomers.[110] This mixture is solid at room temperature, but becomes liquid when exposed to high temperatures. Experiments simulated the conditions of heat transfer, temperature, and coolant flow which would exist in a power reactor. The reactor went critical for the first time on September 17, 1957. OMRE operated at full-power beginning in February of 1958.[111] A second core went critical for the first time on May 9, 1959.

One consequence of the OMRE experiments was the construction at Piqua, Ohio, of the first organic-cooled and moderated nuclear power plant. It went critical in 1963[112]. This plant, built for a

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[107] *Thumbnail Sketch,* November 1958, p. 23.

[108] *Thumbnail Sketch,* November 1958, p. 23.

[109] Robert E. Hine, *Contamination and Decommissioning of the Organic Moderated Reactor Experiment Facility,* EGG-2059 (Idaho Falls: EG&G Idaho, Inc., September, 1980), p. 2.

[110] Terphenyl and diphenyl are hydrocarbons. Those known as polyphenyls were considered for reactor use.

[111] *Thumbnail Sketch,* November 1958, p. 23.

[112] The Piqua, Ohio, plant was part of the second round of

municipally owned utility company, operated until 1966. It shut down when organic matter built up in the reactor core, making it difficult to maintain and operate.[113]

The OMRE experiment was phased out in 1963 after its tests had established the feasibility of operating this type of reactor -- provided that the organic coolant-moderator be kept clean. The reactor was shut down, and the nuclear fuel and reactor vessel internal piping were removed. The facility remained in deactivated condition until 1977.[114]

Experimental Organic Cooled Reactor Extends OMRE Studies

The Experimental Organic Cooled Reactor (EOCR), built adjacent to the OMRE, was designed to advance the OMRE studies. It was viewed as a link between the early OMRE experiments and an economically viable power reactor. "Scaling up" the concept to a commercial size required more advanced experiments. The OMRE had been built at a (relatively low) cost of $1,800,000 and was insufficiently sophisticated to perform such advanced experiments, so the EOCR was planned to advance the concept.

The EOCR was designed by the Fluor Corporation and Atomics International. It provided five large in-pile experimental loops (facilities in the reactor that allowed for the test irradiation of various materials) that would be used to advance the coolant and fuel-element technology for the concept.[115] The facility consisted of a reactor building (STF-601), storage tanks, and pump houses -- all of which went under construction in 1961. The reactor building was the only large building in the complex, the others being pumphouses and other auxiliary buildings. The portion of the building below grade was constructed of reinforced concrete and the portion above grade was built of pumice block covered with corrugated sheet metal.

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demonstrations associated with the Power Reactor Development Program initiated by the AEC to invite industry to develop and finance power reactors.

[113] One source that describes the Piqua, Ohio, plant is *Controlled Nuclear Chain Reaction: The First 50 Years* (La Grange Park, Illinois: American Nuclear Society,1992), p. 41; see also numerous editions of *Thumbnail Sketch*.

[114] Robert E. Hine, *Contamination and Decommissioning of the Organic Moderated Reactor Experiment Facility OMRE* EGG-2059 (Idaho Falls: EG&G Idaho Report EGG-2095, 1980), p. 2.

[115] W.E. Nyer and J.H. Rainwater, *Experimental Organic Cooled Reactor Conceptual Design* (Idaho Falls: Report IDO-16570, December 1959), p. 7.

Construction on the facility was ninety percent complete when the AEC canceled the organic coolant program in December 1962. It had concluded that the concept was not likely to improve significantly the performance of nuclear power plants beyond that already achieved by other reactor concepts. Thus, this reactor never was completed and never went critical.

OMRE and EOCR after 1963

Following the demise of the Organic Reactor Program in 1962 both the OMRE and the EOCR were placed in standby status. In 1977 workers proceeded to decontaminate and dismantle the OMRE and all of its support buildings. This was the first such dismantlement at the INEEL and therefore constituted a learning experience for everyone involved in the procedure. Even in its dismantlement, the OMRE was used for experimental purposes.

The D&D (decontamination and dismantlement) process took two years and ended in September 1979. There were two major objectives to the D&D at OMRE. One was to remove the entire facility by disposing of all contaminated articles and the second was to determine what techniques, procedures and special tools should be developed for other D&D projects.[116] Both objectives were met and demonstrated the need for further research into special tools, decontamination of soils, and ways to meet acceptable standards preventing the release of radioactive materials.

The EOCR, still in standby status, in 1963 was considered for conversion to a water-cooled and -moderated reactor. But this did not occur; the equipment and parts that had been ordered were used elsewhere. During 1978 and 1979 a portion of the building was used as office space auxiliary to the D&D of the OMRE. The facility then was used as a training facility for the security force at the INEEL. The vicinity was equipped for target practice and other security training procedures.

All of the structures at the EOCR site have been demolished. The organic-cooled reactor concept was a significant symbol of the AEC reactor program despite its status as a concept that ended up as "a path not chosen" for commercial development. Pursuant to a Memorandum of Agreement with the Idaho SHPO, photographs were taken of the buildings prior to demoliton in anticipation of HABS/HAER recordation.

[116] Robert E. Hine, *Contamination and Decommissioning of the Organic Moderated Reactor Experiment Facility OMRE* EGG-2059 (Idaho Falls: EG&G Idaho Report EGG-2095, 1980), p. 3.

SubTheme: *Cold War Weapons and Military Applications*
INEEL Area: Naval Reactors Facility (NRF)

The Navy's Quest for Nuclear Propulsion: 1939-1948

The Navy's dream of nuclear power for propulsion predated both the existence of the AEC and the entrance of the United States into World War II. As early as 1939, the Naval Research Laboratory became involved in budding atomic research, and thereafter participated in the Manhattan Project. Navy research, shared with the Army, led to the production of Uranium-235, which the Manhattan Project used for the bomb dropped on Hiroshima.

After World War II, some Naval leaders, particularly Admiral Earle Mills of the Bureau of Ships, envisioned nuclear propulsion as the key to ocean-warfare supremacy. In 1946 Admiral Mills sent Navy researchers to Oak Ridge to learn the fundamentals of nuclear technology. Mills selected Captain Hyman Rickover, known for his excellent work on shipboard electrical problems, as senior officer. Rickover embarked on a career known for combining his formidable personality with the goal of developing nuclear propulsion.[117]

The Atomic Energy Act of 1946 and the formation of the AEC in 1947 obliged the Navy to work in close cooperation with the new civilian agency. Admiral Mills and Captain Rickover worked on procedures for cooperation between Navy and AEC staff. These arrangements stayed essentially the same for the next thirty years. The Navy focused more on engineering, while the AEC oversaw reactor research, initial design, and plant and shipboard safety. The Navy designed, built, and operated its ships. The AEC also received Navy funds for the naval features required on a shipboard plant. All land prototypes of the shipboard nuclear plants were funded by the AEC, with some supporting funds from the Navy. All actual shipboard plants were paid for by the Navy with the exception of the first two -- the submarines USS *Nautilus* and USS *Seawolf*.[118]

Several AEC national laboratories were responsible for developing various aspects of naval nuclear power. The Bettis Laboratory (operated by Westinghouse) near Pittsburgh, Pennsylvania, was chosen as the site for the design and development of a naval nuclear plant. Knolls Laboratory in

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[117] Hewlett, *Atomic Shield*, p. 74-76.

[118] Francis Duncan, *Rickover and the Nuclear Navy* (Annapolis, Maryland: Naval Institute Press, 1990), 4. Hereafter cited as "Duncan, *Rickover*." See also Hewlett, *Atomic Shield*, p. 189.

Schenectady, New York, (operated by General Electric) was the site chosen for an intermediate naval reactor, with technical assistance supplied by the Argonne National Laboratory. Knolls engineers worked on the feasibility of a liquid-metal cooled reactor. Oak Ridge investigated the use of high-pressure, water-cooled reactors. A plant at Shippingport, Pennsylvania, was planned to demonstrate the feasibility of nuclear power for civilian use.

Submarines in the Desert: 1948-1955

After the AEC decided to build the NRTS, it determined that the Navy's water-cooled reactor prototype would be one of the first four projects built at the new testing station (the others being EBR-I, the MTR, and the Chemical Processing Plant). Argonne and Westinghouse designed and developed components for the reactor. The village of West Milton, New York, was chosen for the liquid metal-cooled reactor prototype, since it was close to the Schenectady laboratory. A small-submarine prototype plant was developed later at Windsor, Connecticut, in 1957.[119]

At the NRTS, Rust Engineering Company chose a site for the submarine thermal reactor about five miles north of the MTR site. In August 1950, F.H. McGraw & Company broke ground for the Submarine Thermal Reactor (STR, also referred to as the Mark I or the S1W Prototype -- S for submarine, 1 for first model, and W for the designer, Westinghouse). With this, Idaho's association with the Nuclear Navy officially began. NRTS Manager Leonard E. Johnston and his staff often clashed with Captain Rickover, who came out personally to oversee the construction plans and who missed few, if any, details. In the midst of the Korean conflict, the pressure was on both men to get the prototype operating by 1952.

The buildings at the Navy complex, which eventually became known as the Naval Reactors Facility (NRF), followed the same principles that guided the NPG and CFA: simplicity, ruggedness, and reliability. However simple the designs were, construction was often slow because the building blueprints were not ready on time. The reactor prototype was housed in a large steel building; inside was a full-scale section of a submarine hull surrounded by a 300,000-gallon tank of water. Following Rickover's insistence, the hull was identical to that of a regular Navy submarine, down to its "Battleship Gray" paint.[120]

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[119] Hewlett, *Atomic Shield*, p. 418-419; see also Duncan, *Rickover*, p. 5.

[120] Hewlett, *Atomic Shield*, p. 495-496; see also unpublished binder entitled "Naval Reactors Facility, 1994," on file at INEEL